ESAs Report Outline

- Missions status
  - Sentinel-1
  - Sentinel-2
  - Sentinel-3
  - Sentinel-5P
  - Proba-V

- Fiducial Reference Measurements Activities
Sentinel-1 full mission exploitation capacity based on the routine operations of the 2-satellite constellation gradually achieved.
Sentinel-1 mission status

- **Sentinel-1A nominal routine operations continue**
  - An average of **3 TB of products** is generated daily
  - Support to various activations from the Copernicus Emergency Service and from the International Charter Space and Major Disasters
  - Many promising results based on S1A data obtained in various application fields and from institutional, scientific, commercial players

- **Sentinel-1B commissioning activities in-progress**
  - First SAR data acquired and successfully processed less than 3 days after launch
  - Commissioning activities on-going according to plans
  - Start of Sentinel-1B operations after the In-Orbit Commissioning Phase Review (IOCR), planned on 14 September 2016
S1 mission capacity will increase with S1B in operations and the integration of the EDRS service. Estimated daily volume of S1 core products in early 2017 is **10 TB / day**.
• Sentinel-1 has already proved to be a very relevant source of data for land cover monitoring.

• Sentinel-1A routinely provides since end 2014 a full mapping of Europe (EU/ESA/EEA-39):
  • Every 12 days both in ascending and descending orbits, in dual polarisation VV+VH
  • In practise, depending on latitudes / swath overlaps, more frequent coverage is ensured in Europe

• Sentinel-1B will allow to increase this European coverage by a factor 2, ie the S1 constellation will provide a full coverage at least every 6 days, both in ascending and descending orbits

→ Dedicated presentation on Cal/Val on Wed. 7th.
Sentinel-1 SAR Constellation Instrument Calibration and Performance Verification, I. Navas-Traver et al
Sentinel-1
http://www.esa.int/Our_Activities/Observing_the_Earth/Copernicus/Sentinel-1/Sentinel-1_provides_new_insight_into_Italy_s_earthquake

S1A and S1B before and after the 24 August 2016 earthquake: 15 August, 21 August and 27 August 2016.
The result shows vertical ground subsidence, reaching about 20 cm in correspondence to the Accumoli area, and lateral movement of up to 16 cm.
The blue line indicates the location of the fault trace.

Copyright Contains modified Copernicus Sentinel data (2016)/ESA/CNR-IREA
Solar panel on the Copernicus Sentinel-1A satellite hit by a millimetre-size particle in orbit on 23 August. Thanks to onboard cameras, ground controllers were able to identify the affected area. **There has been no effect on the satellite's routine operations.**
**Sentinel-2 : Mission Overview**

- **Spacecrafts**: 2 operating in twin configuration
- Sentinel-2A launched on 23rd June 2015
- **Orbit**: Sun-synchronous at 786 km (14+3/10 revs per day), with LTDN 10:30 AM
- **MultiSpectral Instrument (MSI)**: operating in pushbroom principle, filter based optical system
- **Spectral bands**: 13 (VIS–NIR–SWIR spectral domains)
- **Spatial resolution**: 10m / 20m / 60m
- **Swath**: 290 km
Currently observation of average ~14 min/orbit (i.e. >80% of average observation time in full operations)

- Systematically Europe, Greenland & Africa on every orbit = 10 days (at equator)
- The Rest of the World (RoW) within a certain interval

- Observation plan is published ahead of every repeat cycle as kml at https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/acquisition-plans

Since 3 May: revisit frequency increased to 20 days Rest of World!
## Sentinel-2 Products

<table>
<thead>
<tr>
<th>Name</th>
<th>High-level Description</th>
<th>Production</th>
<th>Preservation Strategy</th>
<th>Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Level-1B</strong></td>
<td>Top-of-atmosphere radiances in sensor geometry</td>
<td>Systematic</td>
<td>Long-term</td>
<td>~27 MB (each 25x23km²)</td>
</tr>
<tr>
<td><strong>Level-1C</strong></td>
<td>Top-of-atmosphere reflectance in cartographic geometry</td>
<td>Systematic</td>
<td>Long-term</td>
<td>~500 MB (each 100x100km²)</td>
</tr>
<tr>
<td><strong>Level-2A</strong></td>
<td>Bottom-of-atmosphere reflectances in cartographic geometry (prototype product)</td>
<td>On user side* (using Sentinel-2 Toolbox**)</td>
<td>N/A</td>
<td>~600 MB (each 100x100km²)</td>
</tr>
</tbody>
</table>

*: Systematic global production of L2A is currently being prepared

**: [https://sentinels.copernicus.eu/web/sentinel/toolboxes/sentinel-2](https://sentinels.copernicus.eu/web/sentinel/toolboxes/sentinel-2)
Sentinel-2A
Ever increasing range of applications

- Forests & Carbon, Vegetation monitoring
- Geology
- Emergency management
- Land cover classification/CORINE, IMAGE2006, IMAGE2009 etc.
- Glaciers & Ice
- Coastal zones/bathymetry
- Regional to Urban Applications
- Global Land use & change
- Water quality
Max-NDVI composite of TOA reflectance from all available Sentinel-2 images acquired from August 2015 to April 2016

(~32 TByte of data)
Sentinel-2A Measured Performances

L1 Geometry

**Geolocation**

- **Method**: Matching L1 images with perfectly geolocalized reference images (GCPs).
- **Results**: Performance analysed on 107 products including 708 GCPs.

The latest performance estimation, with processing baseline 02.04 deployed on 30th of May, is now **8m** at 95.5% vs. 14.6m previously, well below requirements (20m at 95.5%). The performances improvement results from an improvement of the yaw pointing bias correction.
Improvement using a GRI (Global Reference Image)

- **Objective**: To obtain a full repeat cycle dataset of well-localized mono-spectral Level-1B images (band 4) which will be used as reference images in the processing, allowing to: improve geolocation, ensure coherence between orbits and ensure multi-temporal registration.

First GRI validation results

Pre-validation made internally.
Geolocation estimated to 8m CE95
Sentinel-2A Measured Performances: Radiometry

**On-board sun diffuser**

**Absolute Radiometry**

- **Method:** Rayleigh scattering using ocean targets, ground measurements over RadCalNet sites, and inter-comparison with Landsat-8.
Sentinel-2A Performance summary

- **Excellent product data quality:**

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Description</th>
<th>Measured performance</th>
</tr>
</thead>
</table>
| **Absolute geolocation**
   (without ground control points)                | The geo-location uncertainty shall be better than 20 m at 2σ confidence level (without Ground Control Points). | < 12.36 m at 2σ      |
| **Multi-spectral Registration**                  | The inter-channel spatial co-registration of any two spectral bands shall be better than 0.30 of the coarser achieved spatial sampling distance of these two bands at 3σ confidence level. | < 0.26 pixel at 3σ   |
| **Absolute radiometric uncertainty**             | The absolute radiometric uncertainty shall be better than 5 % (goal 3%).    | B1 to B9: < 5%±2%    |
| **SNR**                                          | The Signal-to-Noise Ratio (SNR) shall be higher than specified values (see Table 2.2 in this document) | All bands compliant with > 20% margin |

- **Next main steps:**
  - GRI generation and validation on-going.
  - To complete on-going reprocessing campaign.
Sentinel-3: launch

Launched on a Rockot from Plesetsk, Russia, at 17:57 GMT on 16 February 2016
Sentinel-3: mission

- **Sentinel-3 A** is the first of a series of 4 satellites ensuring 20 years of operational ocean and land monitoring.
- Developed by ESA for the European Commission and co-operated by ESA/EUMETSAT.
- The spacecrafts carry four main instruments:
  - OLCI: Ocean and Land Colour Instrument
  - SLSTR: Sea and Land Surface Temperature Instrument
  - SRAL: SAR Radar Altimeter
  - MWR: Microwave Radiometer.
- These are complemented by three instruments for Precise Orbit Determination (POD):
  - DORIS: a Doppler Orbit Radio positioning system
  - GNSS: a GPS receiver, providing precise orbit determination and tracking multiple satellites simultaneously
  - LRR: to accurately locate the satellite in orbit using a Laser Retro-Reflector system.
Orbit type: Repeating frozen SSO
Repeat cycle: 27 days (14 + 7/27 orbits/day)
LTDN: 10:00
Average altitude: 815 km
Inclination: 98.65 deg
OLCI spectral/radiometric calibration

OLCI is a self-calibrating instrument using on-board diffusers:

- Every ~2 weeks routine with 1st white diffuser
- Every ~3 months with 2nd white diffuser for ageing
- Spectral calibration: Erbium Doped Diffuser (for spectral calibration)

It is being changed to perform the calibration at fixed geometry (i.e. about every two weeks)
Sentinel-3A:
Radiometric gain variation from white diffuser – Mean across track gains (ACRI)

- Calibration gains show time variability believed to be related to:
  - Star tracker anomaly => pointing model
  - Uncertainties of diffuser BRDF model (already known from on-ground)
- Stability improves with time.
CNES (SADE/MUSCLE) and ESTEC (DIMITRI) used for independent assessment:

- Consistent results making use of different methods / implementations
- Spectral consistency
  - OLCI radiances might be slightly higher than expected but more data over longer period of time is needed to confirm and monitor the evolution
Signal-to-Noise Ratio (SNR)

- SNR performance are scaled down from $L_{\text{cal}}$ to typical water radiance ($L_{\text{ref}}$) with 2 different methods.
- Results compliant, downscaling to be confirmed by ongoing analysis of EO images.

ESTEC (J.-L. Bezy)

ACRI (L. Bourg)
**OLCI in-flight spectral calibration**

**Spectral calibration** is established using:
- The on-board Erbium Doped Diffuser,
- Fraunhofer Lines (for validation),
- Oxygen O2A (for validation).

Acquisitions scenario:
- Orbit \( n = \text{Diffuser-1 Cal (Band setting j)} \)
- Orbit \( n+1 = \text{Diffuser-Er (Band setting j)} \)

Measurements over Natural target

OLCI was programmed in a way to observe the O2A absorption features over bright Earth targets.

Fraunhofer lines on non-doped diffuser

White Diffuser Measurements

O2A spectrum

BC

ACRI – L. Bourg

Fraunhofer lines on non-doped diffuser

White Diffuser Measurements

OLCI was programmed in a way to observe the O2A absorption features over bright Earth targets.

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White Diffuser Measurements

O2A spectrum

BC

ACRI – L. Bourg

Fraunhofer lines on non-doped diffuser

White Diffuser Measurements

OLCI was programmed in a way to observe the O2A absorption features over bright Earth targets.
In flight spectral calibration results

- Pre-flight characterisation confirmed in-flight (<0.15nm)
- Small temporal trends since beginning of the mission (comparable to MERIS)
- Spectrally fully compliant

Brockmann Consult – R. Preusker
In flight geometric calibration results

- After early mission pointing issues were fixed (e.g.: star tracker software), OLCI spatial feature matching with a Landsat reference imagettes database led to a first geometric calibration resulting into approximately sub-pixel accuracies. More data needed to fit a thermo-elastic model (seasonal variations) and further improve the calibration.
Sentinel-3 SLSTR First Image over Egypt 03/03/2016

+ 

Last AATSR image over Egypt 07/04/2012
Large irrigation fields in the desert (healthy vegetation appears in red)
VIS-SWIR radiometric monitoring based on VISCAL

- VISCAL (white diffuser) is illuminated once per orbit
- Oscillations in VIS channels caused by build up of water ice on VIS relay optics
- Same behaviour as seen on ATSR-2, AATSR
- VISCAL measurements are used to account for the long term instrument sensitivity changes (and short term changes due to the water ice contamination)
Radiometric calibration

- Vicarious methodologies using stable reference sites (e.g. SADE, DIMITRI) revealed a very good spectral consistency in the VIS and a possible ~+3% bias (wrt MERIS/MODIS-A) in the VIS.
- Radiometric issue in the SWIR (~-10% at 1.6 μm and ~-40% at 2.2 μm). The issue is strongly suspected to be linked to the pre-flight calibration.

--- Investigation on-going. Current status shows about 10% in SWIR.
NEDT values agree with pre-launch calibration and are well within specification,

Good initial long term stability,

No effects on performance due to the build up of water ice have been observed.
TIR radiometric calibration

- TIR calibration is based on 2 black bodies (‘cold’ and ‘warm’ to cover dynamic range)
- Both black bodies temperature show good orbital stability < 0.1K
- Gradients on black body plates in nominal configuration are stable.
**OLCI/SLSTR Conclusions**

- **OLCI and SLSTR SNR is compliant with specification**

- **OLCI Calibration gains show time variability**
  - Partly related to star tracker anomaly and uncertainties of BRDF model (already known from on-ground)
  - Stability seems to improve with time

- **OLCI Vicarious calibration shows spectrally/spatially/dynamically consistent results, however a ∼+3% bias.**
  - Actions are in place to further investigate this point (e.g., yaw maneuvers to characterize BRDF diffuser in flight and perform calibrations at fixed geometry, periodic noise correction in ground processing) during next phase.

- **SLSTR Radiometric calibration will require longer period monitoring**

- **SLSTR TIR Radiometric Noise**
  - NEDTs agree with pre-launch data and within specification

- **SLSTR TIR Radiometric Gains and Offsets**
  - Black body signals provide ‘continuous’ measurement of dark signals and the instrument is within specification
  - Show good orbital stability

- **Black Body Calibration System fully functional**
  - Absolute accuracy:
    - Difference in measured counts between the two black bodies during cross over test suggest calibration accuracy < 0.2K => compliance. Seems confirmed by IASI SNOs.

- **Geometric calibration is ongoing with the prospect of delivering sub-pixel accuracy. Long term monitoring needed to derive thermo-elastic model.**
OLCI/SLSTR Data availability

• IOCR – In Orbit Commissioning Phase Review – was completed in July 2016

• Level 1B data will be released in September 2016

• Level 2 validation is on going

• Level 2 data release planned for the end of 2016
  • Marine Product distributed by EUMETSAT
  • Land Product distributed by ESA


• Sentinel-3 Validation Team Meeting will take place 22-24 November 2016 at ESRIN
S-3A STM status:
- Overall status of the mission sensors and science products is good
- L1 data operationally qualified
- Overall L2 data quality is already good over the ocean
- Additional assessment of L2 data and corrections of anomalies in ground processor is requested before L2 data release to the user community
- Expected official L1 & L2 data release in Q3 2016

SWH is quite GOOD (Needs slight fine-tuning)

Wind Speed looks OK (Except for few outliers)

Reduced noise in SAR mode vs LRM as expected
   Improved spectral information content for SLA at ocean mesoscale

Very promising from the first SRAL measurements!
Sentinel-5P

- S5p is narrowing the gap between Envisat and Sentinel-5
- Towards 40 years of similar atmospheric composition observations!
The ESA Sentinel-5 Precursor (S5P) is a pre-operational mission focusing on global observations of the atmospheric composition for Air Quality and Climate.

The TROPOspheric Monitoring Instrument (TROPOMI) is the payload of the S-5P mission and is jointly developed by The Netherlands and ESA.

The planned launch date for S5P is **Q1/2017** with a 7-year design lifetime.

Background mission with global daily coverage.

**TROPOMI**

- UV-VIS-NIR-SSWIR push-broom grating spectrometer.
- Spectral range: 270-500 nm, 675-775 nm, 2305-2385 nm
- Spectral Resolution: 0.25-1.1 nm
- Observation Mode: Nadir, global daily coverage, ground pixel 7x7km² at nadir
- Orbit: Sun synchronous, 824 km, 13:30 hr dayside equator crossing time.

**CONTRIBUTION TO Copernicus**

- O₃: total and tropospheric column, profile
- NO₂: tropospheric and total column
- CO: total column
- SO₂: total column
- CH₄: total column
- Aerosol: absorbing index, type, optical depth
- H₂O: tropospheric column
- H₂O: total column
- BrO: total column
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Data Product</th>
<th>Vertical Resolution</th>
<th>Accuracy</th>
<th>Precision</th>
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<tbody>
<tr>
<td>Ozone</td>
<td>Ozone Profile</td>
<td>6 km</td>
<td>10-30%</td>
<td>10%</td>
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<td>Total Ozone</td>
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<td>3.5-5%</td>
<td>1.6-2.5%</td>
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<td></td>
<td>Tropospheric Ozone</td>
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<td></td>
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<td>NO₂</td>
<td>Stratospheric NO₂</td>
<td>strat column</td>
<td>&lt;10%</td>
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<td>Tropospheric NO₂</td>
<td>trop column</td>
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<td>SO₂</td>
<td>SO₂ enhanced</td>
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<td>0.15-0.3 (0.06-0.12) DU</td>
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<td>Total SO₂</td>
<td>total column</td>
<td>30-50%</td>
<td>1-3 (0.4-1.2) DU</td>
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<td>Formaldehyde</td>
<td>Total HCHO</td>
<td>total column</td>
<td>40-80%</td>
<td>1.2e16 (4e15)</td>
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<td>CO</td>
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<td>15%</td>
<td>&lt;10%</td>
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<tr>
<td>Methane</td>
<td>Total CH₄</td>
<td>total column</td>
<td>1.5%</td>
<td>1%</td>
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<td>Cloud</td>
<td>Cloud Fraction</td>
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<td>0.05</td>
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<td>Albedo (Optical Thickness)</td>
<td>total column</td>
<td>&lt;20%</td>
<td>0.05 (10)</td>
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<td>Cloud Height (Pressure)</td>
<td>total column</td>
<td>&lt;20%</td>
<td>&lt;0.5 km (&lt;30hPa)</td>
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<td>SNPP VIIRS Cloud data</td>
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<tr>
<td>Aerosol</td>
<td>Aerosol Layer Height</td>
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<td>&lt;100hPa</td>
<td>&lt;50hPa</td>
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<td>Aerosol Type</td>
<td>total column</td>
<td>~1 AAI</td>
<td>&lt;0.1 AAI</td>
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</tbody>
</table>
SENTINEL Data Policy

- **EU Copernicus Regulation**: full, open and free data policy, defining responsibilities for ESA and EUMETSAT and overall financial envelope
- **ESA Copernicus data access** is ensuring that all Sentinels core products are accessible to all users online
  - Any user can **self-register** at [sentinels.copernicus.eu](http://sentinels.copernicus.eu)

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**Scientific Data Hub**
- **Self Registration**
  - > 33,000 Users
- **No Rolling Policy Applied**
- **Sentinel-1A NTC**, **Sentinel-2A L1C**
  - 03-Oct-2014
  - Max 2 Concurrent Downloads

**Collaborative Data Hub**
- **11 Collaborative Users**
  - Node 1: 30 days
  - Node 2: 9 days
- **4 Data Hub Relay Users**
  - Sentinel-1A NRT & NTC
  - Sentinel-2A L1C
  - 03-Oct-2014
  - 16-Nov-2015
  - Max 10 Concurrent Downloads

**International Access Hub**
- **4 Users**
  - 30 Days
  - Sentinel-1A NTC
  - Sentinel-2A L1C
  - 01-Dec-2015
  - Max 10 concurrent downloads

**Copernicus Services Data Hub**
- **108 Users**
  - No Rolling Policy Applied
  - Sentinel-1A NRT & NTC
  - Sentinel-2A L1C
  - 01-Dec-2015
  - No limits
Proba-V Mission Status, Calibration, Products and Applications

Mission
✓ Launched on 7 May 2013 for 5 years
✓ Global daily vegetation monitoring
✓ Spectral bands: Blue, Red, NIR, SWIR
✓ Operations running very smoothly

Calibration
✓ Radiometry (vicarious) better than 5% with 3% stability
✓ Geometry better than 60m with GCP

Products and Applications
✓ Composites TOA, TOC (1, 5, 10 days) delivered to users at 1km, 333m, 100m
✓ Reprocessing on-going mainly to improve cloud screening
✓ Increasing number of users for a wide range of applications (land and water)
✓ Large interest in 100m data (5 days revisit) for crop monitoring and LCLU
Proba-V Consistency, Continuity and Data Exploitation

Consistency and Continuity
- Primary source of data to Copernicus Global Land for retrieval of biophysical variables: FAPAR, Fcover, LAI, ...
- Consistency with VGT demonstrated
- Crucial for seamless transition from SPOT-VGT archive to S3A+B

Data Exploitation
- Mission Exploitation Platform (MEP) for accessing full VGT+PV archive
  
  [https://proba-v-mep.esa.int](https://proba-v-mep.esa.int)

- Projects on-going exploiting 100m for LC and coastal water applications

Cloud detection Round Robin
- Started in Feb 2016 (1 year)
- 9 Research Institutes
- Various techniques: NN, Bayesian, ...
- Validation data: representative large set of visually classified pixels
What are FRM?

Fiducial Reference Measurements (FRM) are (Donlon, S3VT meeting):
- the suite of independent ground measurements
- that provide the maximum Return On Investment (ROI) for a satellite mission
- by delivering, to users,
- the required confidence in data products,
- in the from of independent validation results and satellite measurement uncertainty estimation,
- over the entire end-to-end duration of a satellite mission.

The defining mandatory characteristics of an FRM are:
- FRM measurements have documented SI traceability via round-robin inter-calibration of instruments.
- FRM measurements are independent from the satellite retrieval process.
- An uncertainty budget for all FRM instruments and derived measurements is available and maintained.
- FRM measurement protocols and community-wide management practices (measurement, processing, archive, documents etc.) are defined and adhered to.

→ FRM allow a proper understanding of the validation results and FRM comparison between Validation measurements
FRM4 activities

In framework of CEOS WGCV we have started a number of activities to qualify validation measurements as FRM. This is the concept of FRM4.

The principles are simple:

- Validation instruments are characterised and intercalibrated in laboratories where the reference instrument are characterised and traceable to standards (metrology institutes like NPL)
- Measurements protocols are established
- Field in-situ measurements (on sea, land…etc…) following protocols. Uncertainties budget are derived
- Analysis and intercomparison between measurements
- Workshop and Publication

Planned or Running Activities:

- FRM4ALT – started - http://www.frm4alt.eu - Altimetry
- FRM4GHG – started - The focus of the "Fiducial Reference Measurements for Ground-Based FTIR Greenhouse Gas Observations" (FRM4GHG) project is the intercomparison of instruments and harmonization of products and retrievals from ground-based FTIR systems
- FRM4DOAS – started - The "FRM for Ground-Based DOAS Air Quality Observations" (FRM4DOAS) project aims at the harmonization of the retrievals from UV-Visible ground-based spectrometers, e.g., MAXDOAS or Pandora, in view of reaching the standards of FRMs for NO2 and ozone.
- FRM4SAR – to be started in 2016

…others to come….

For more information, please visit: https://earth.esa.int/web/sppa/activities
THANK YOU

Further information available at:

http://sentinels.copernicus.eu
https://earth.esa.int/web/sppa/activities